

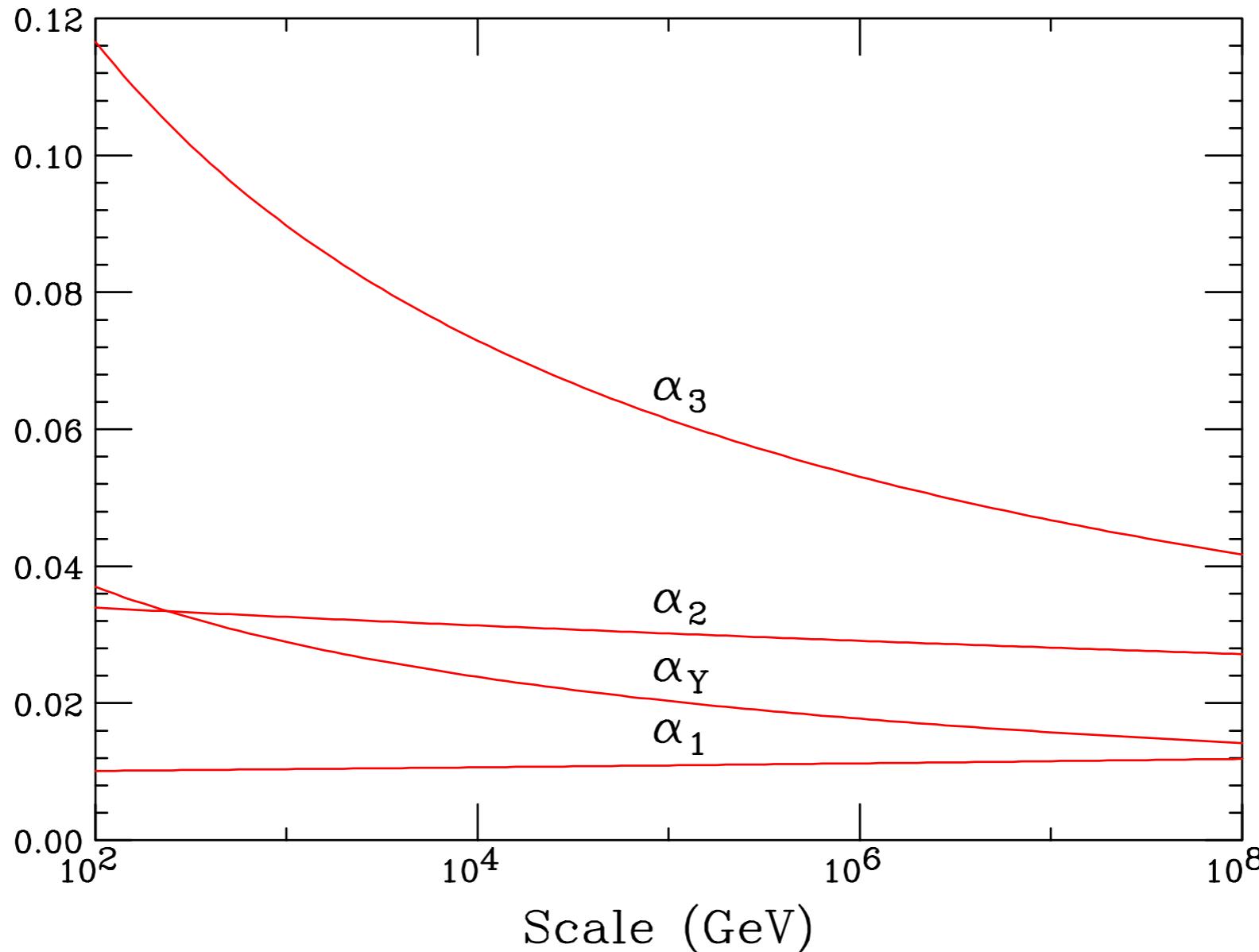
Electroweak Effects in Parton Showers at High Energy

Bryan Webber
Cambridge

- Our approach
- Polarisation effects
- Double log evolution
- Soft coherence
- Results and summary

Work with CW Bauer, N Ferland, D Provasoli, N Rodd

Standard Model couplings

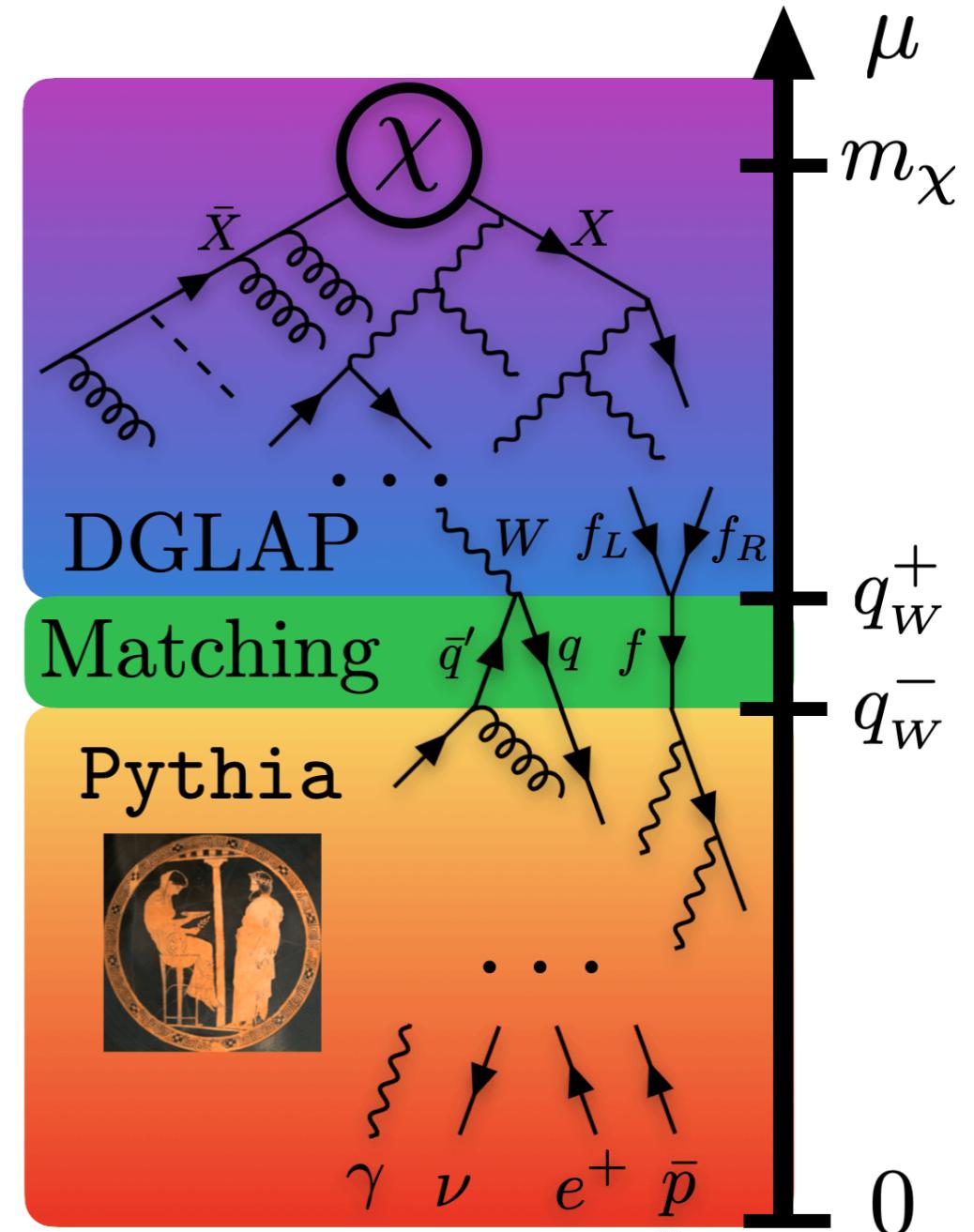


- Well above EW scale, at $q \gg m_W$, we have approximately unbroken $SU(3) \times SU(2) \times U(1)$
- Corrections $\sim m_W/q$

Our Approach

Our Approach (Heavy DM decay)

- Sequential stages:
 - DM decay $\chi \rightarrow X\bar{X}$ (any SM particles)
 - Unbroken SM above EW scale $q_W \sim 100$ GeV
 - Matching across EW scale (heavy decays)
 - Pythia below EW scale
 - Decays to absolutely stable: γ, ν, e, p



Bauer, Rodd, BW, 2007.15001

<https://github.com/nickrodd/HDMspectra>

Polarisation Effects

Polarized Splitting Functions

- For any gauge interaction $G=\text{SU}(3), \text{SU}(2), \text{U}(1)$
(neglecting azimuthal correlations)

$$P_{f_L f_L, G}^R(z) = P_{f_R f_R, G}^R(z) = \frac{2}{1-z} - (1+z),$$

$$P_{H H, G}^R(z) = \frac{2}{1-z} - 2,$$

$$P_{V_+ f_L, G}^R(z) = P_{V_- f_R, G}^R(z) = \frac{(1-z)^2}{z},$$

$$P_{V_\pm H, G}^R(z) = \frac{1}{z} - 1,$$

$$P_{V_- f_L, G}^R(z) = P_{V_+ f_R, G}^R(z) = \frac{1}{z},$$

$$P_{H V_\pm, G}^R(z) = \frac{1}{2}z(1-z).$$

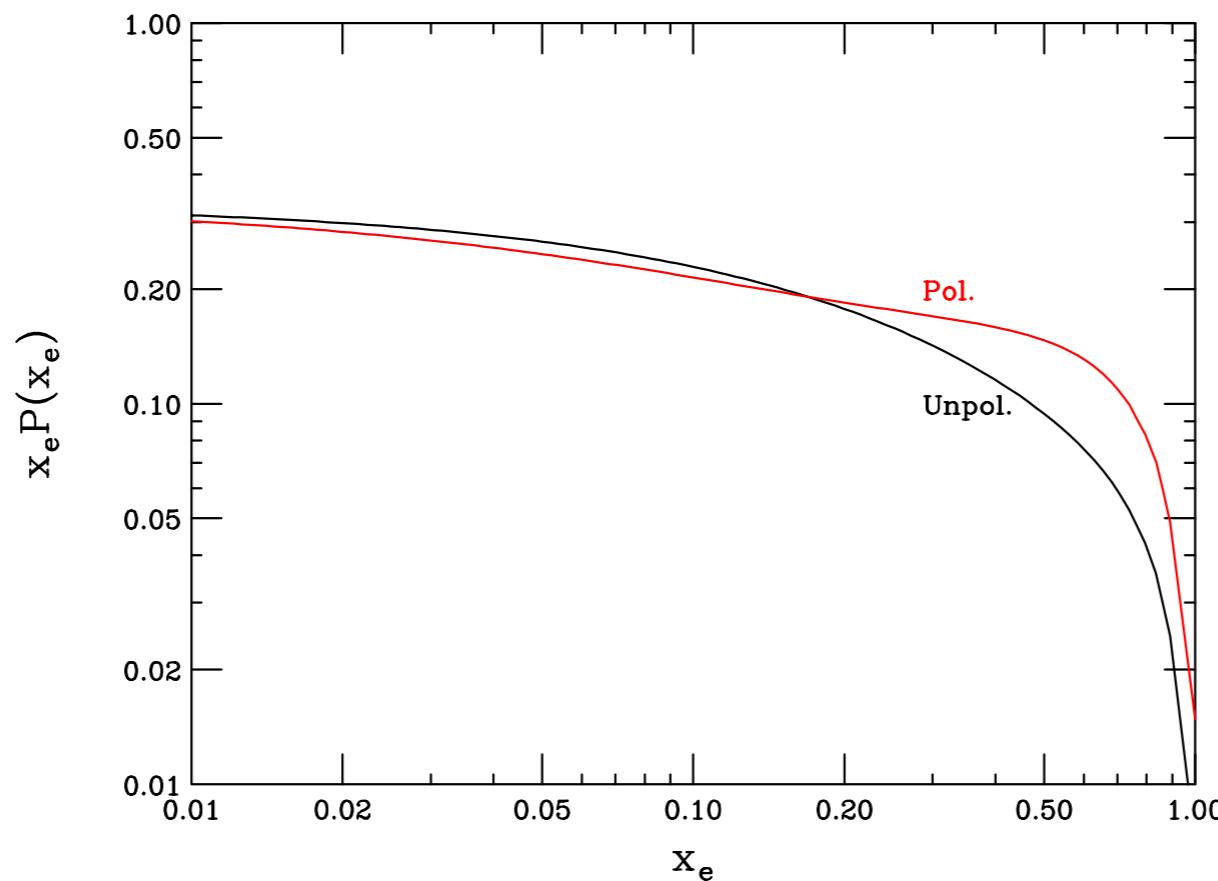
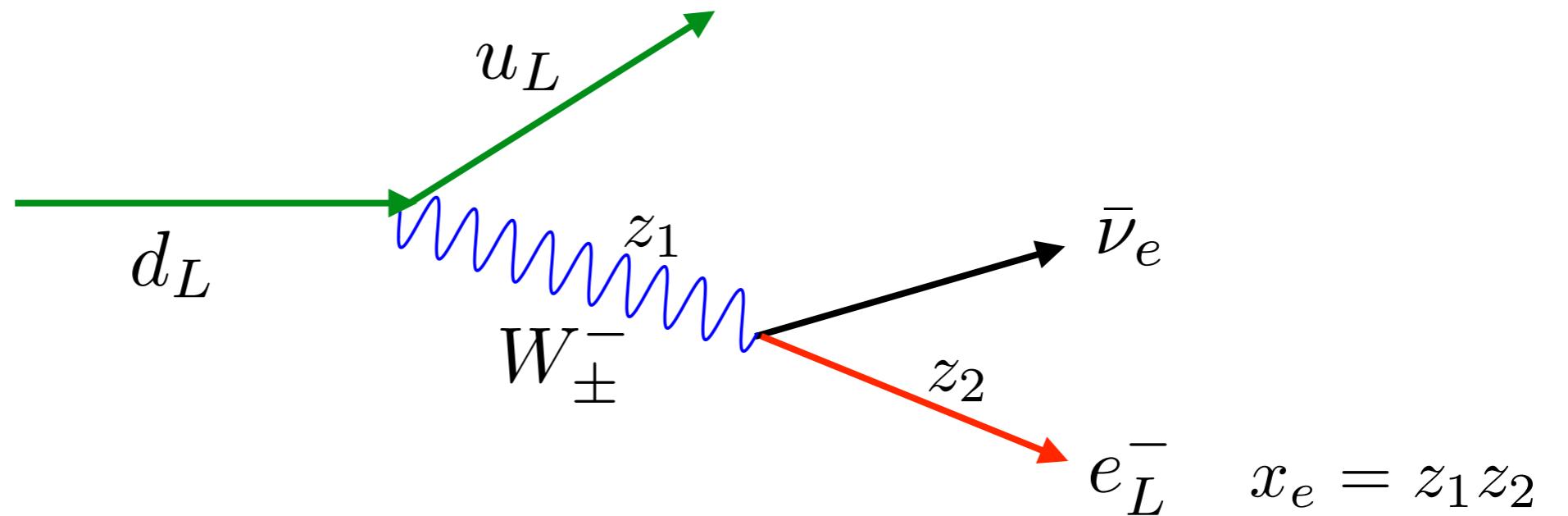
$$P_{f_L V_+, G}^R(z) = P_{f_R V_-, G}^R(z) = \frac{1}{2}(1-z)^2,$$

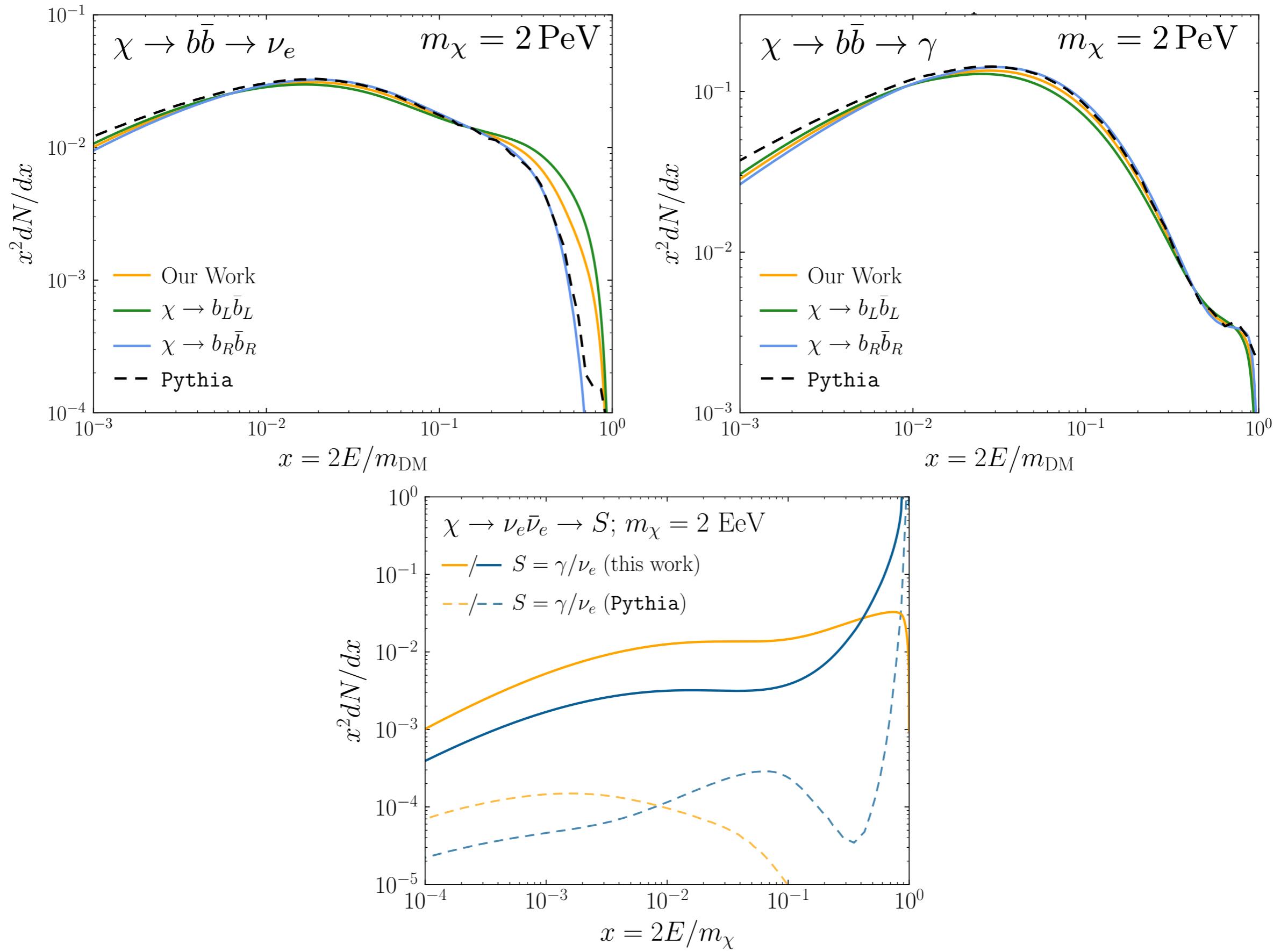
$$P_{f_L V_-, G}^R(z) = P_{f_R V_+, G}^R(z) = \frac{1}{2}z^2,$$

$$P_{V_+ V_+, G}^R(z) = P_{V_- V_-, G}^R(z) = \frac{2}{1-z} + \frac{1}{z} - 1 - z(1+z),$$

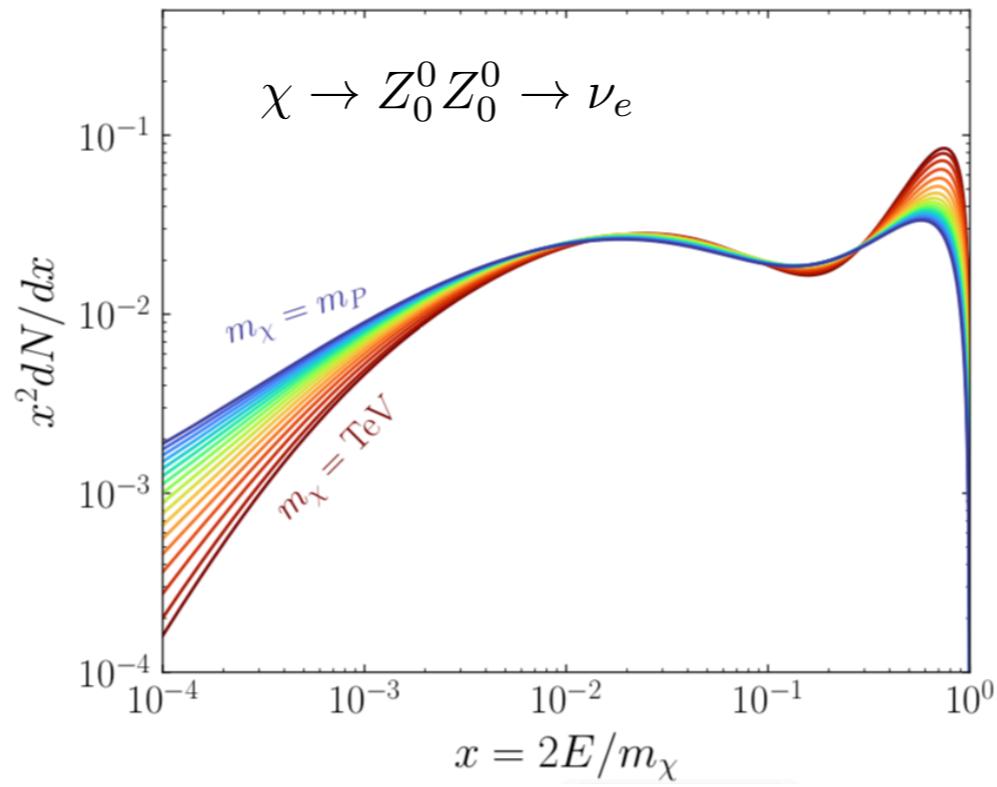
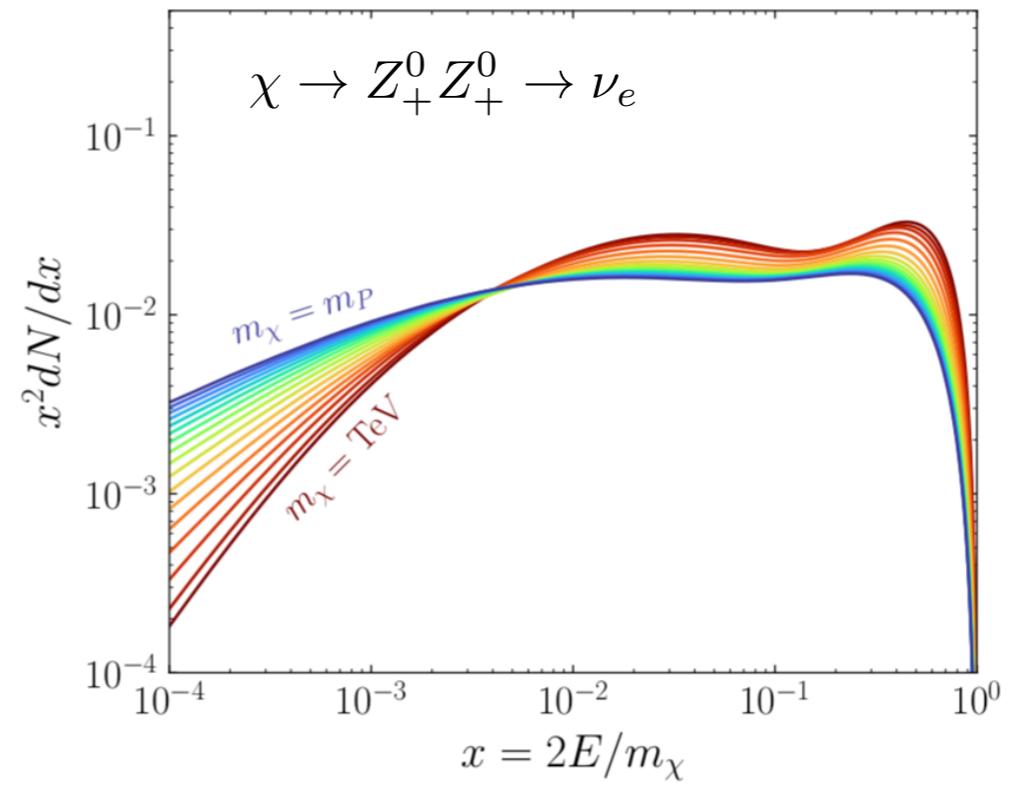
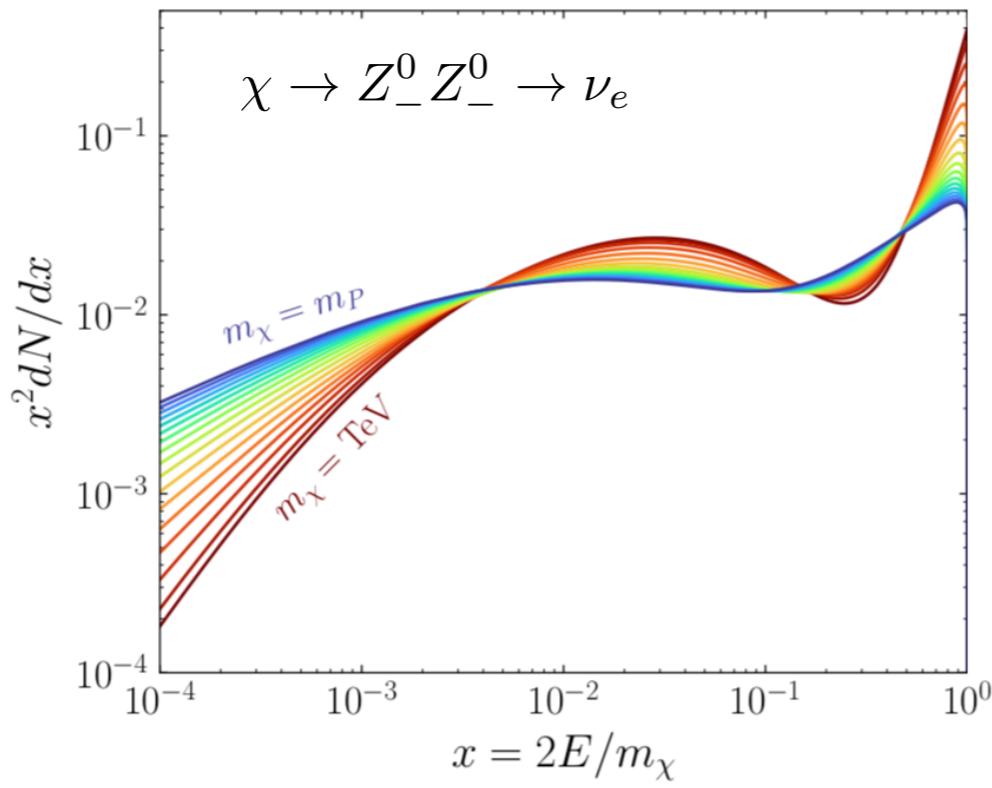
$$P_{V_+ V_-, G}^R(z) = P_{V_- V_+, G}^R(z) = \frac{(1-z)^3}{z},$$

- Polarisation affects spectra





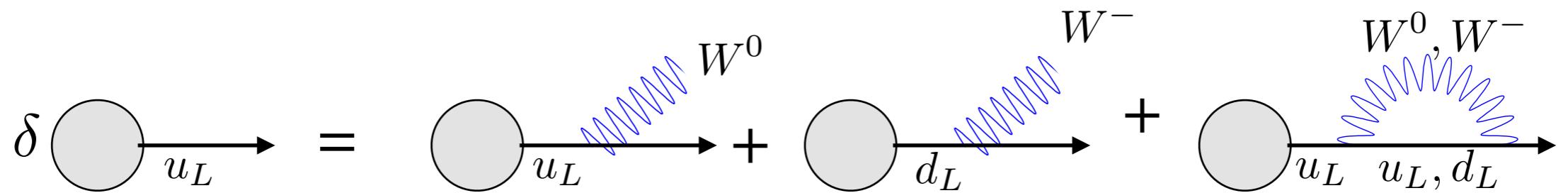
- Big changes when EW important



- Effects of Z polarisation

Double-log evolution

- Real-virtual emission mismatch leads to **double logarithms** of q/m_W



$$q \frac{\partial}{\partial q} u_L(x, q) = \frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} \frac{dz}{z} P_{ff}(z) \left[\frac{1}{3} u_L(x/z, q) + \frac{2}{3} d_L(x/z, q) - z u_L(x, q) \right]$$

$$q \frac{\partial}{\partial q} d_L(x, q) = \frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} \frac{dz}{z} P_{ff}(z) \left[\frac{1}{3} d_L(x/z, q) + \frac{2}{3} u_L(x/z, q) - z d_L(x, q) \right]$$

- Define $Q^\pm = \frac{1}{2} (u_L \pm d_L)$

$$q \frac{\partial}{\partial q} Q^+(x, q) = \frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} \frac{dz}{z} P_{ff}(z) [Q^+(x/z, q) - z Q^+(x, q)]$$

$$q \frac{\partial}{\partial q} Q^-(x, q) = -\frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} \frac{dz}{z} P_{ff}(z) \left[\frac{1}{3} Q^-(x/z, q) + z Q^-(x, q) \right]$$

- Q^+ has DGLAP (single-log) evolution
- Q^- has double-log damping (asymptotic symmetry)

$$q \frac{\partial}{\partial q} Q^-(x, q) = -\frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} \frac{dz}{z} P_{ff}(z) \left[\frac{1}{3} Q^-(x/z, q) + z Q^-(x, q) \right]$$

- Define $F(q) = \int_0^1 dx x Q^-(x, q) = \int_0^1 dx x [u_L(x, q) - d_L(x, q)]$
- Then $q \frac{dF}{dq} = -\frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} dz P_{ff}(z) \frac{4}{3} F(q)$
where $C_F \int_0^{1-m_W/q} dz P_{ff}(z) \sim \frac{3}{2} \ln \left(\frac{q}{m_W} \right)$ $[C_F = 3/4 \text{ for SU}(2)]$
- Hence

$$F(q) \sim F(m_W) \exp \left[-\frac{\alpha_2}{\pi} \ln^2 \left(\frac{q}{m_W} \right) \right]$$
- For LLA resummation: $\alpha_2 \rightarrow \alpha_2(q(1-z))$
- Evolution variable is crucial!

$$q \frac{\partial}{\partial q} Q^-(x, q) = -\frac{\alpha_2}{\pi} C_F \int_0^{1-m_W/q} dz z P_{ff}(z) \left[\frac{1}{3} Q^-(x/z, q) + z Q^-(x, q) \right]$$

- Define $F(q) = \int_0^1 dx x Q^-(x, q) = \int_0^1 dx x [u_L(x, q) - d_L(x, q)]$
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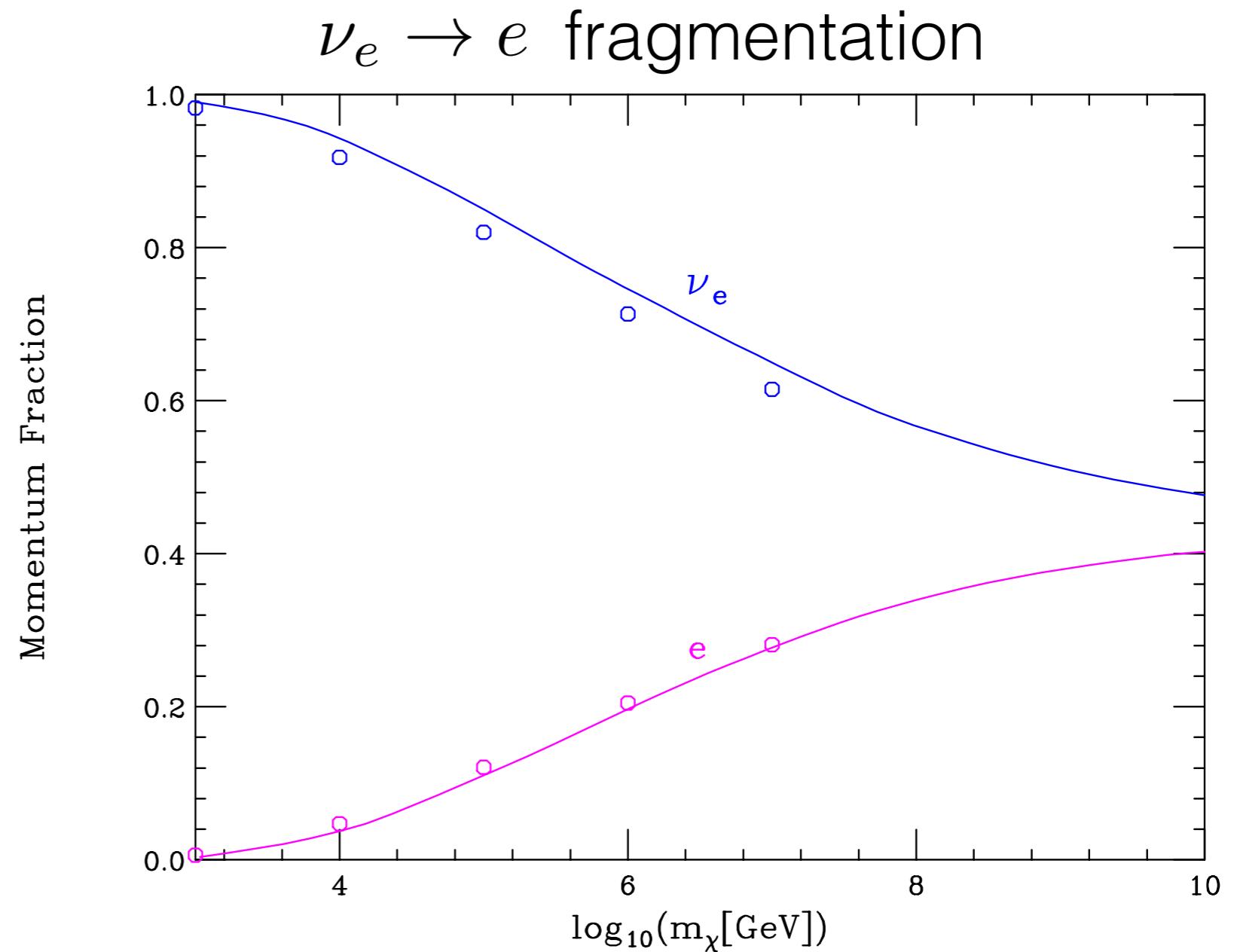
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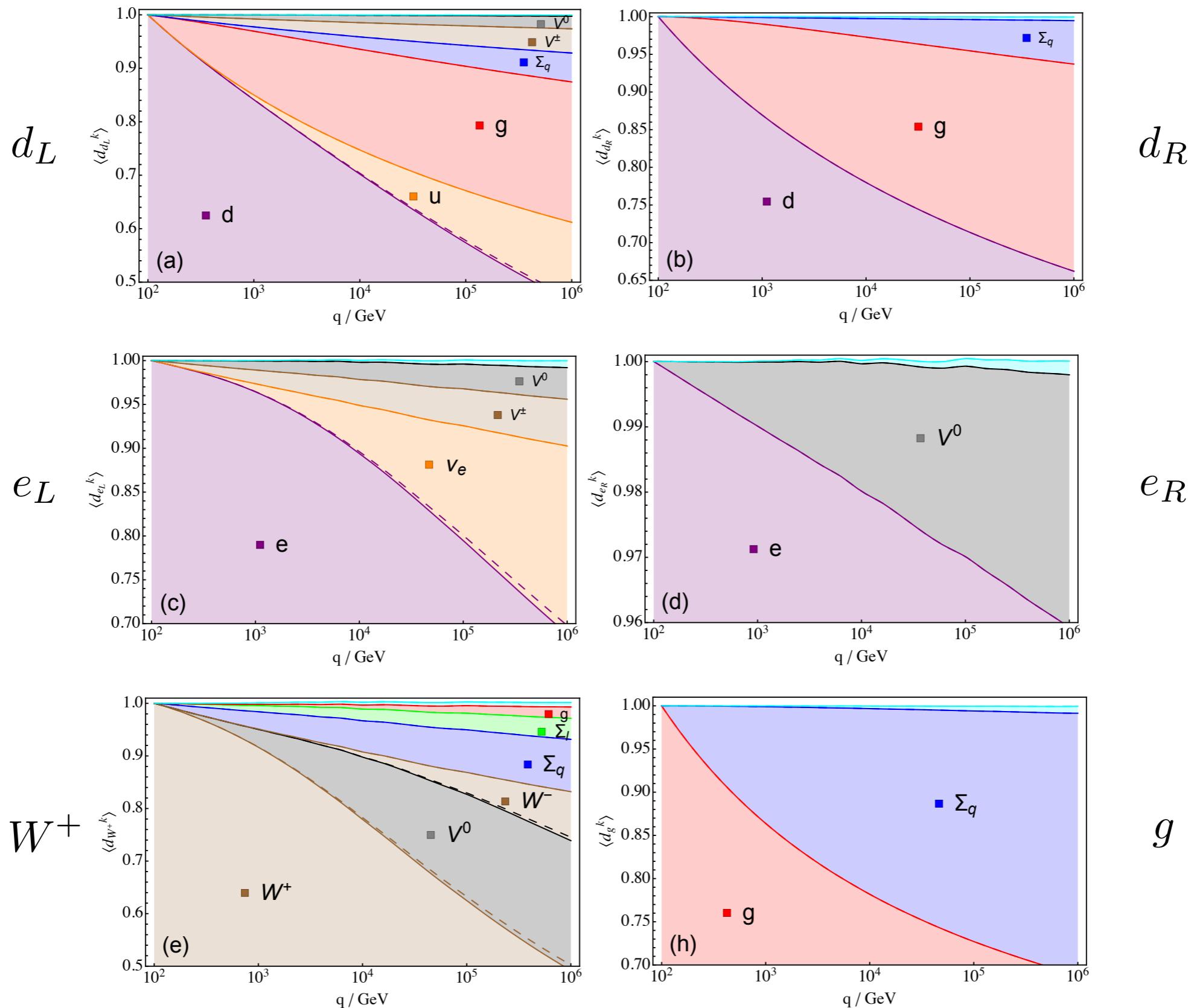
- For LLA resummation: $\alpha_2 \rightarrow \alpha_2(q(1-z))$
- Evolution variable is crucial! Angular-ordered parton shower

Double-log Evolution

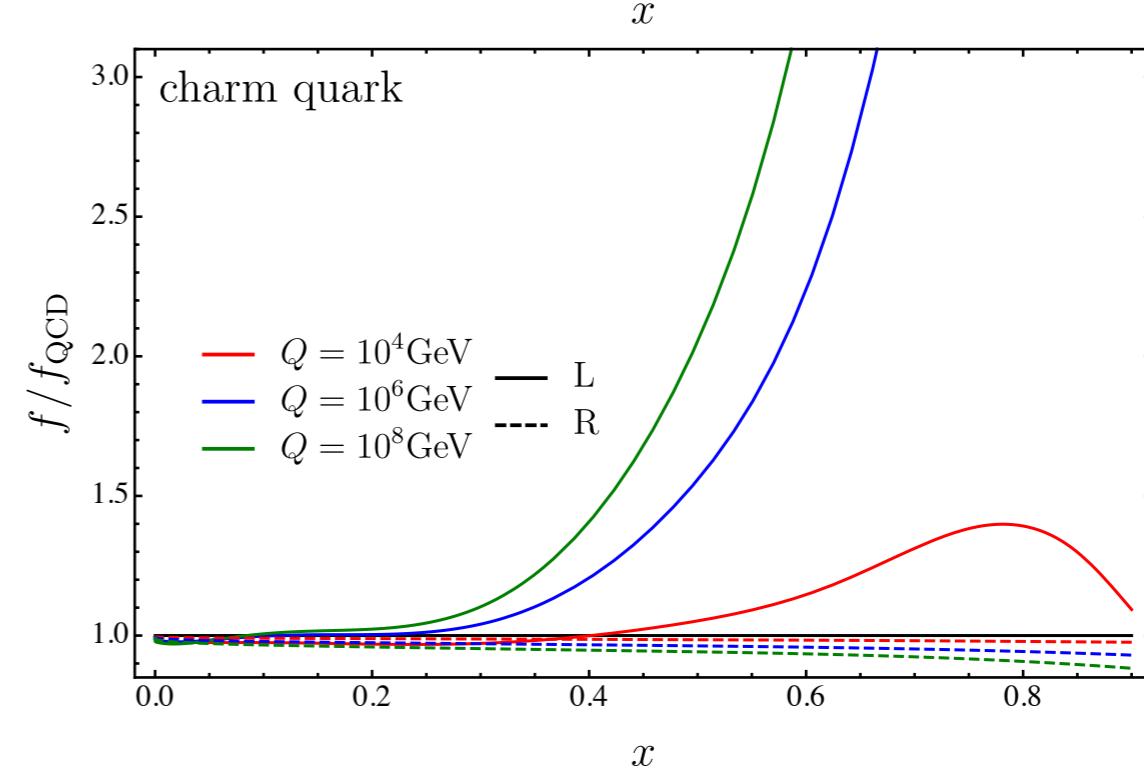
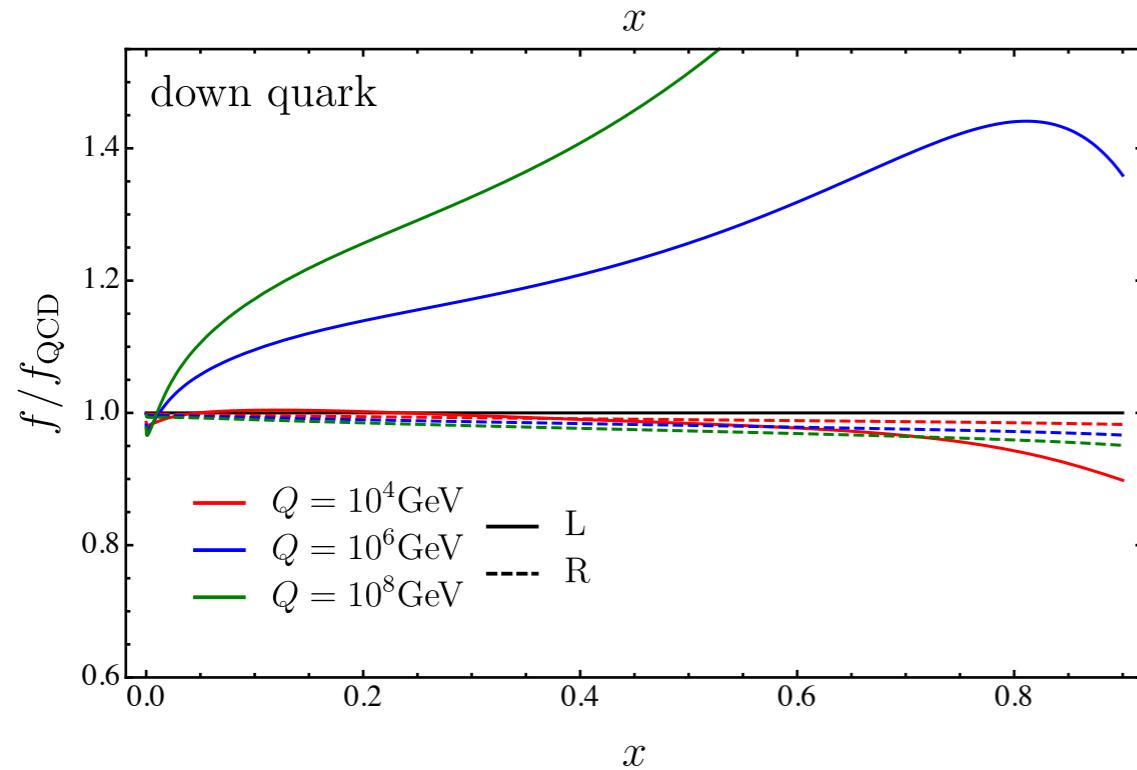
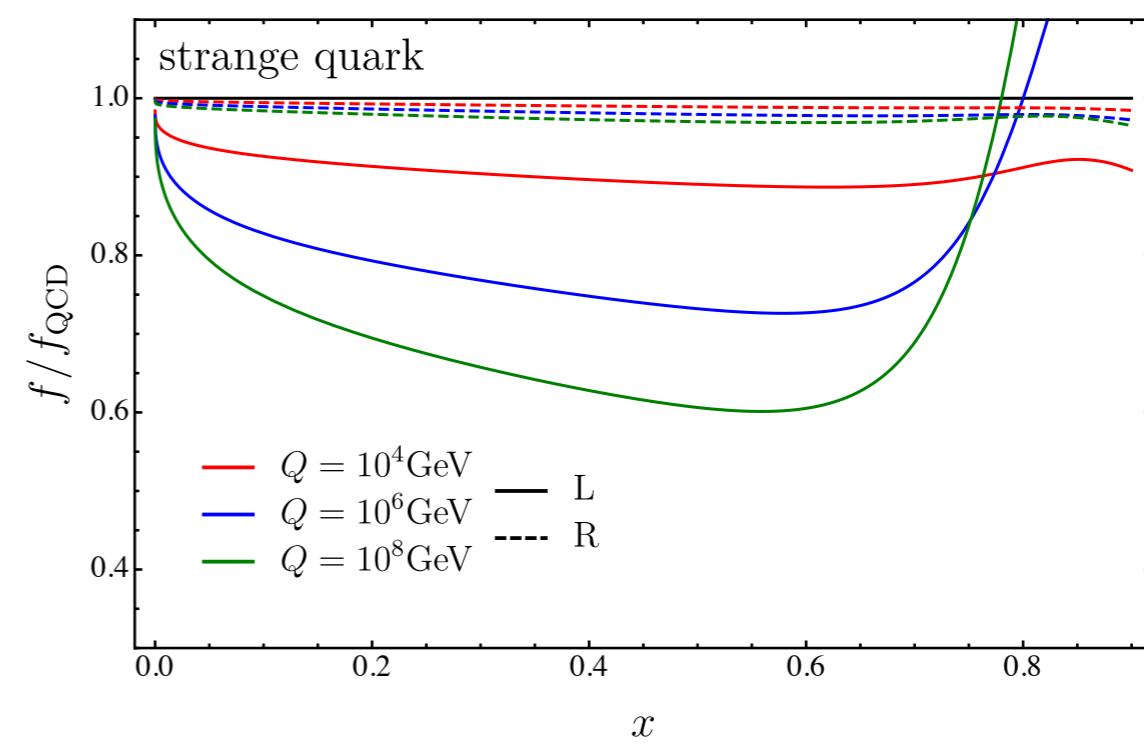
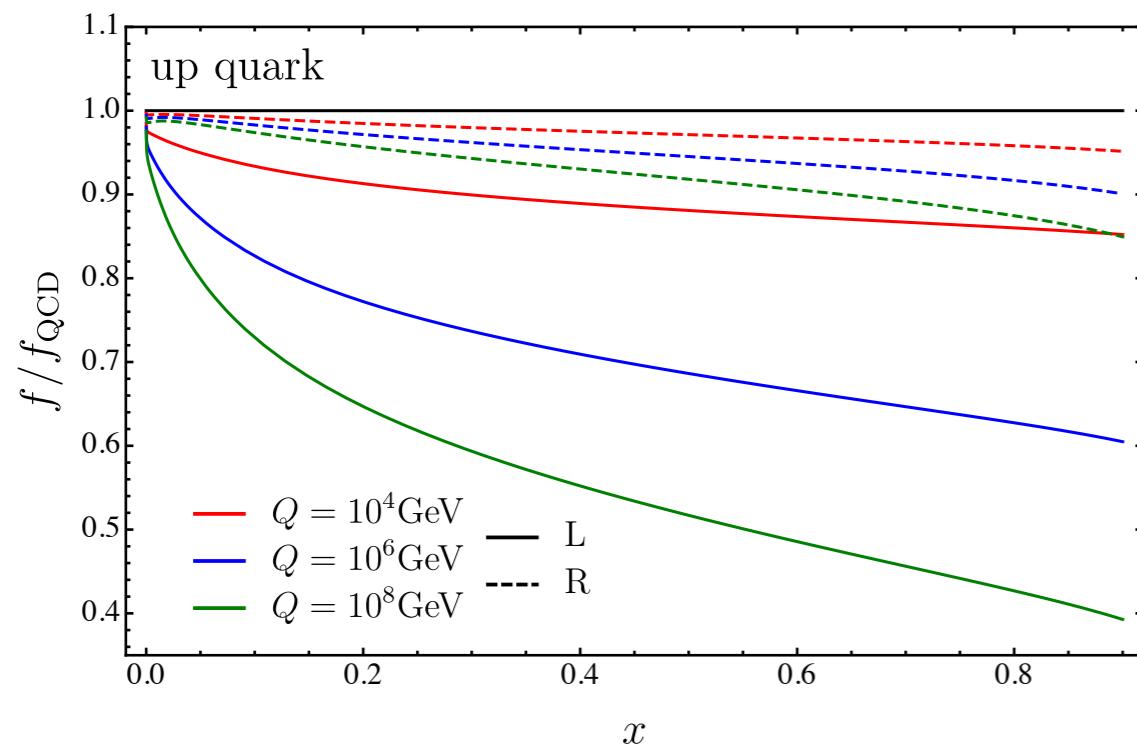
- Curves = DGLAP
- Points = EWPS (prelim.)



Momentum fractions in jets

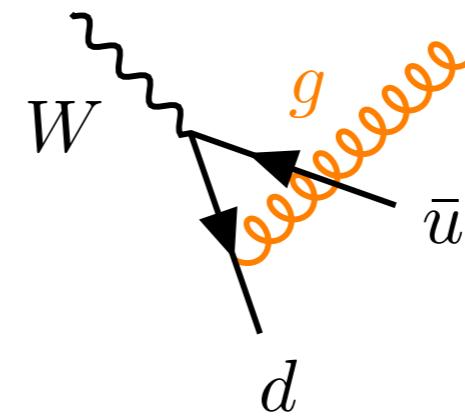
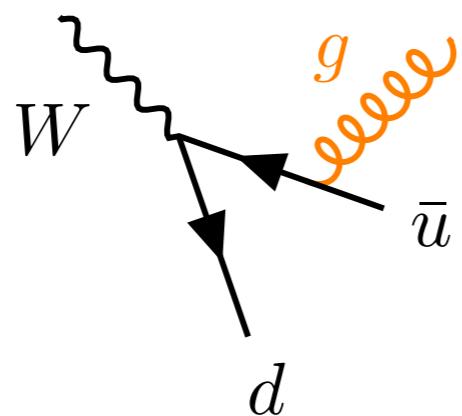


- Similarly in initial-state showering (PDF evolution)
- u_L-d_L (& s_L-c_L) has double-log damping



Soft Coherence

Soft Coherence



- Important difference between QCD ISR & FSR
- Small x logs imply angular ordering, leading to small- x suppression of FSR (only)
- Same must occur in any unbroken gauge theory

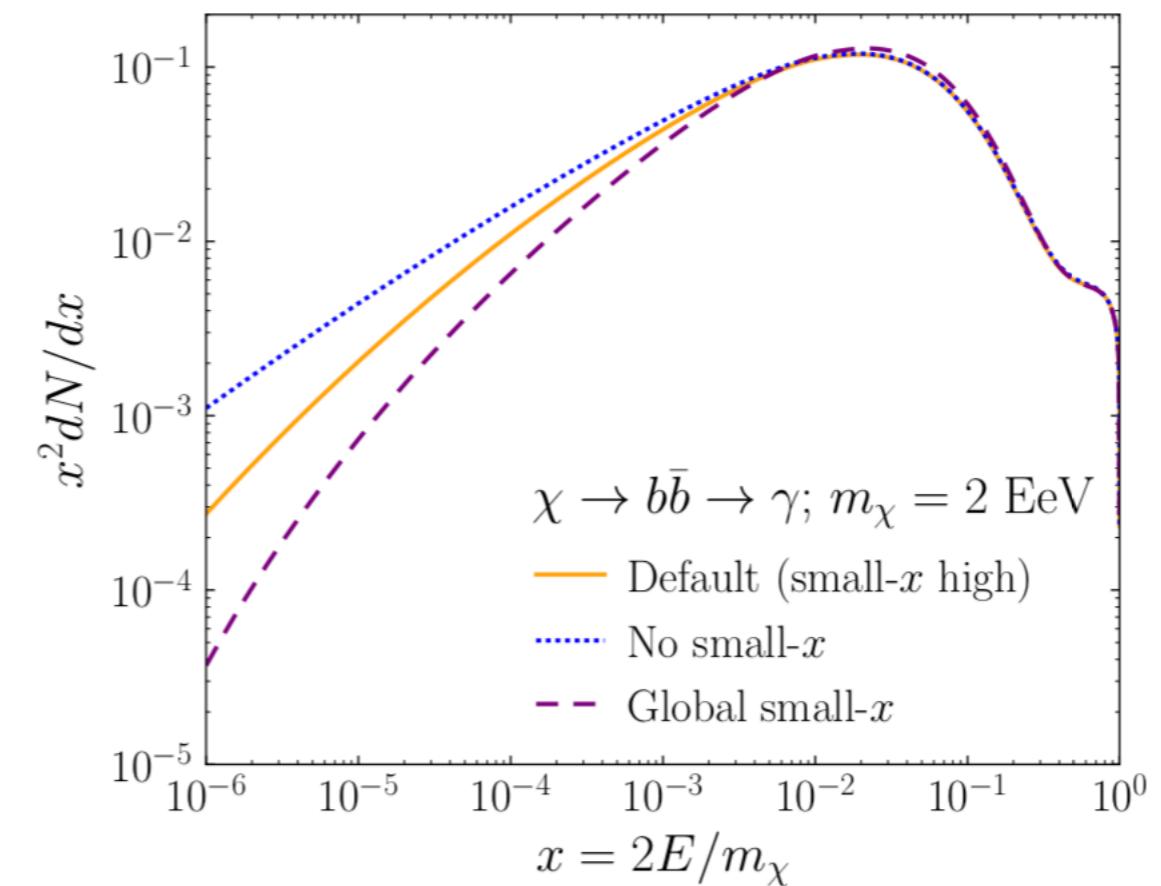
- Gluon fragmentation function satisfies DGLAP evolution equation at scale $q=xQ$

$$x D_g(x; Q) = \delta(1 - x) + \sum_{n=1}^{\infty} \frac{(C_A \alpha_3 / \pi)^n}{n!(n-1)!} \left(\ln \frac{Q^2 x^2}{Q_0^2} \right)^n \left(\ln \frac{1}{x} \right)^{n-1}.$$

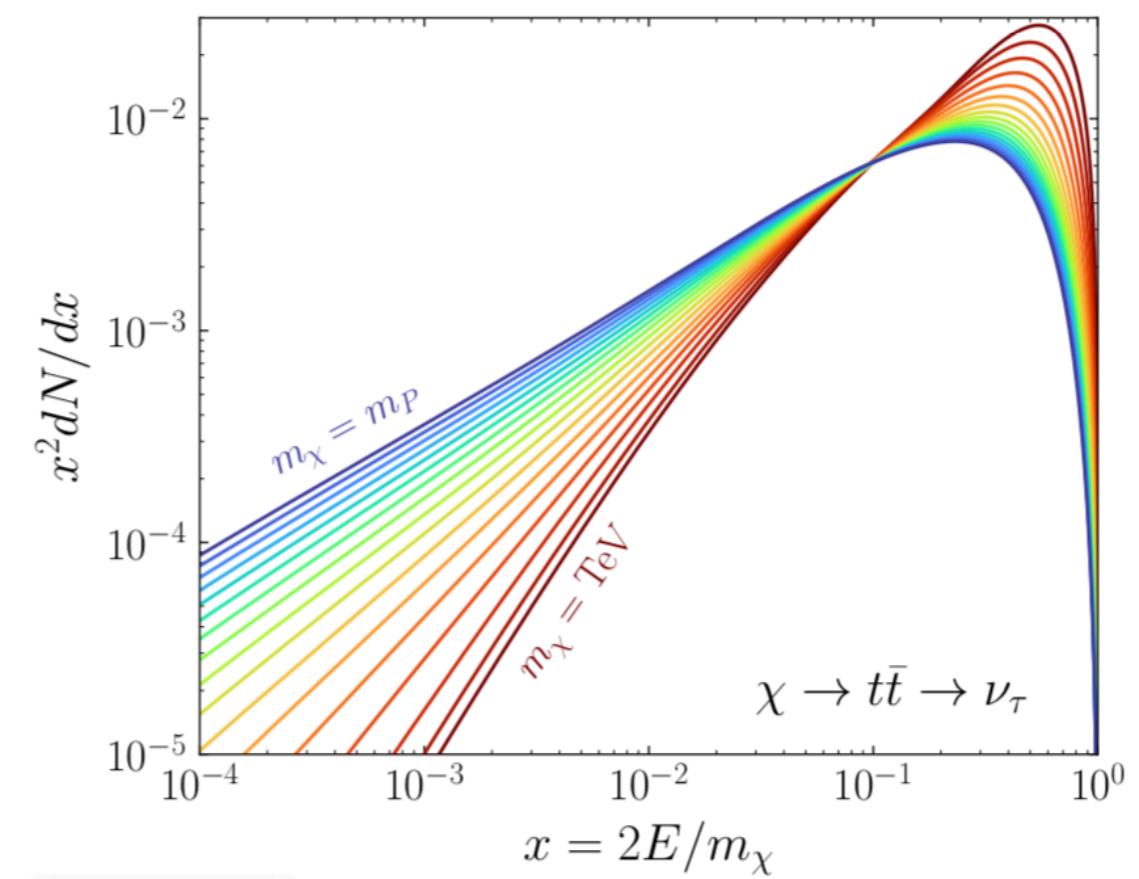
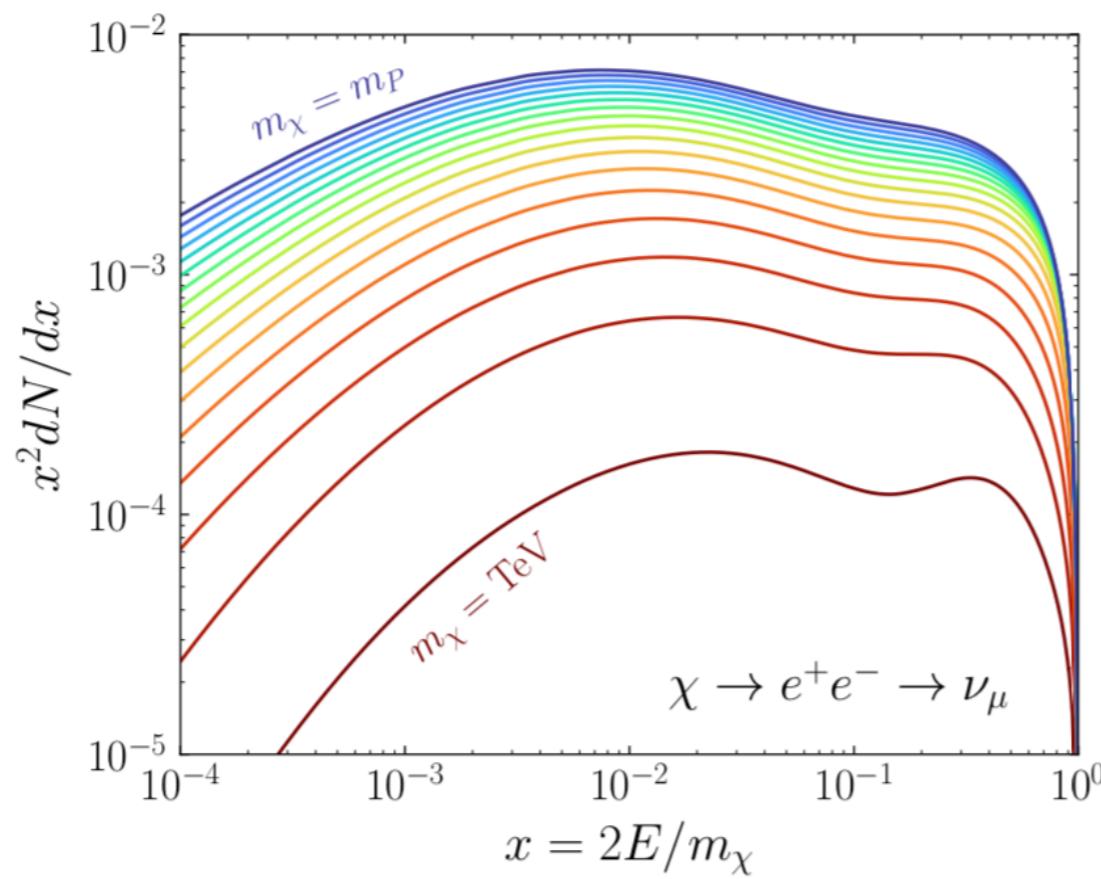
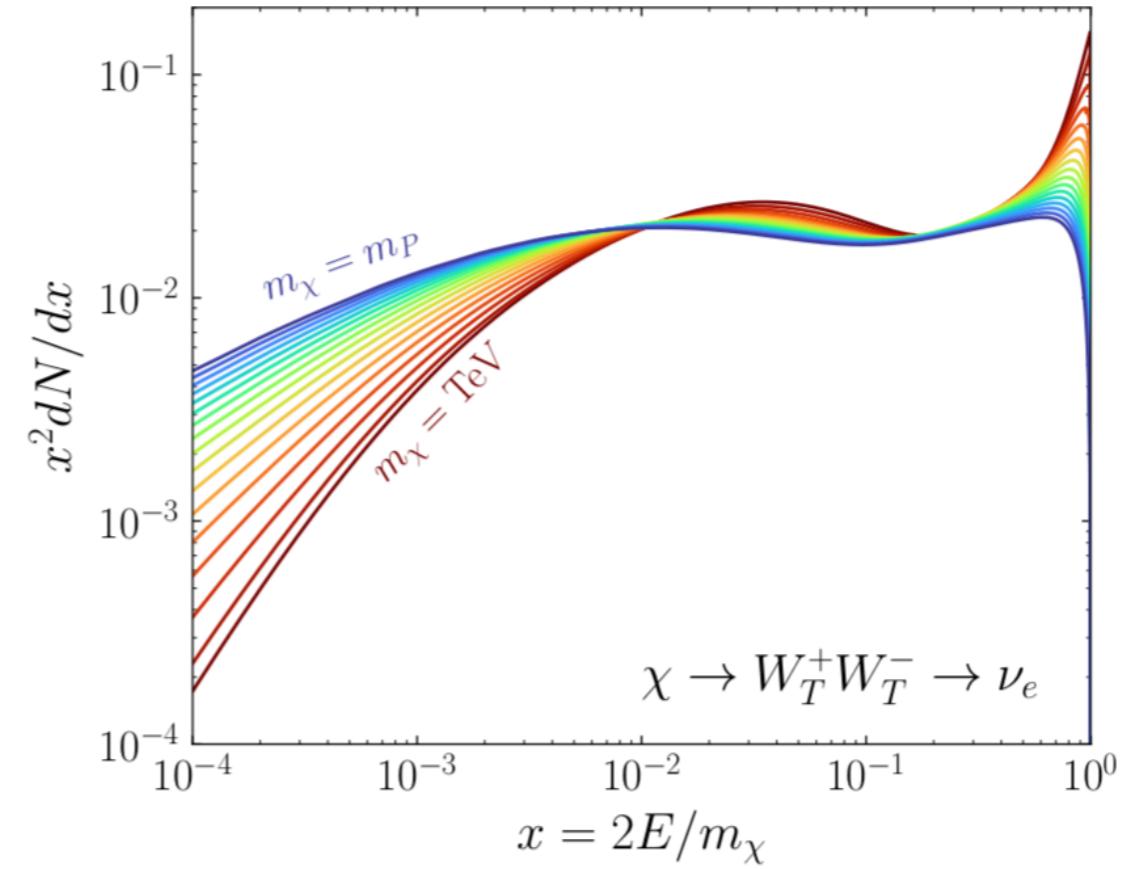
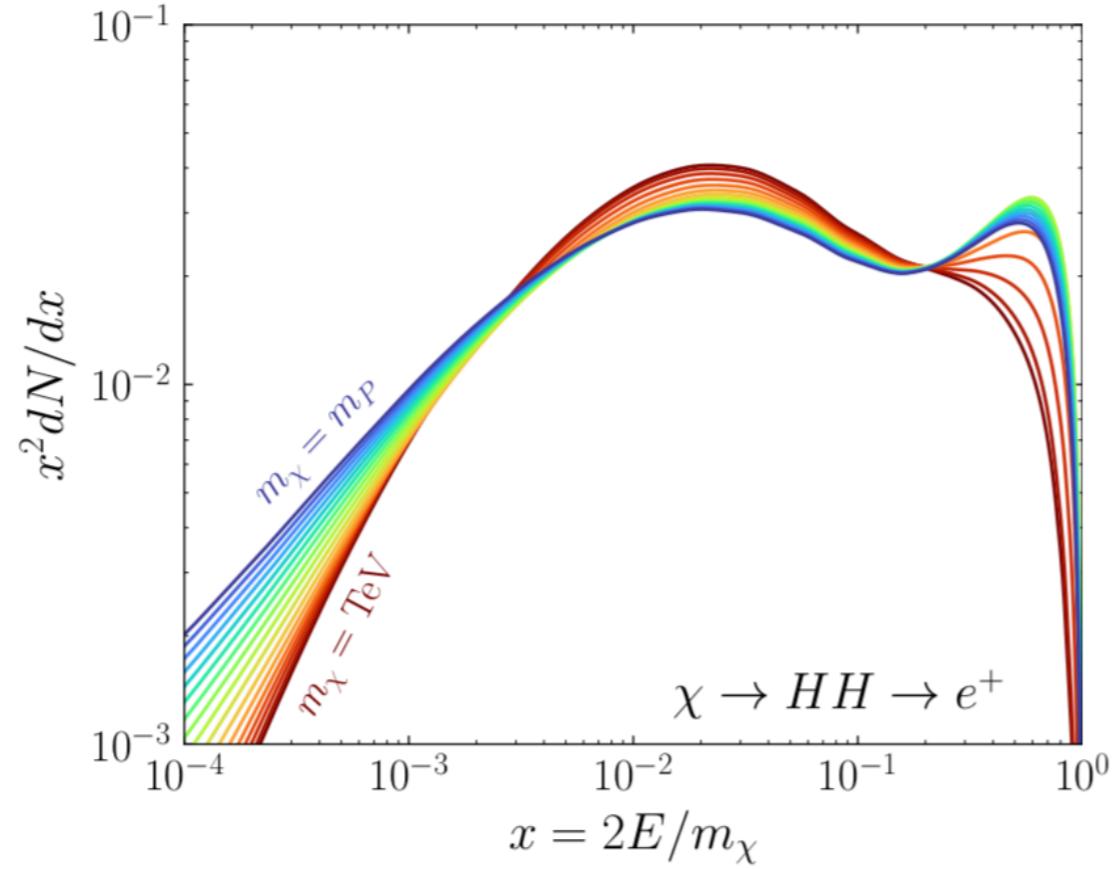
- Solve DGLAP, replace $D(x,Q)$ by $D(x,xQ)$

- We assume same for full unbroken SM

- Main source of uncertainty



More Results



Summary

- Our approach: unbroken SM evolution matched to broken theory at EW scale
 - Currently SM fragmentation functions matched to Pythia
- Novel EW features:
 - Self-polarization, helicity-dependent spectra
 - Double-logarithmic evolution
 - Soft gauge boson coherence (needs more study)
- Full SM parton shower under construction

Thanks for your
attention!